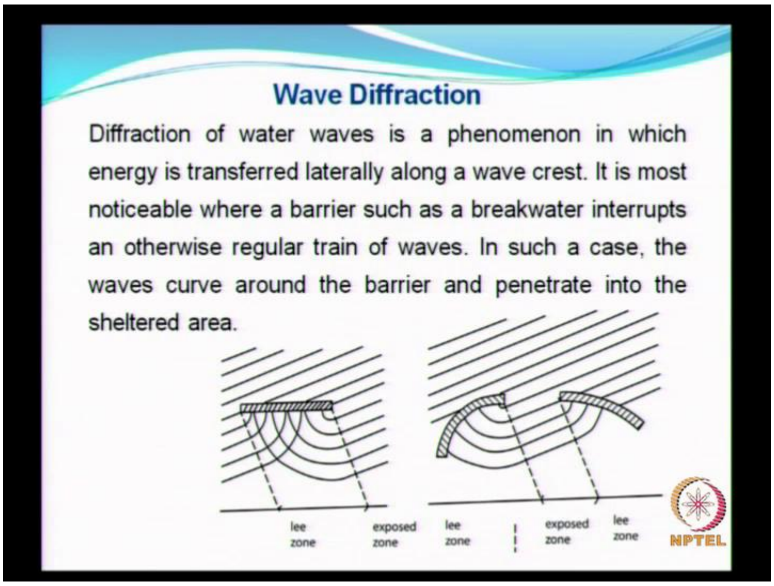
Coastal Engineering
Prof. V. Sundar
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 1
Wave Deformation
Lecture - 2
Wave deformation – II

(Refer Slide Time: 00:24)



Now, we will see, what is the phenomenon of wave diffraction? So, the definition of diffraction is given on the slide. This is the phenomena in which the energy is transferred laterally along the wave crest; that is we have seen earlier, wave refraction wherein when the wave is moving; you have the transfer of energy form deep to shallow waters in the direction of wave propagation. And in that we have assumed that there is no propagation of waves in the lateral direction, butthis may not be true.

So, there will be some amount of energy which is getting transmitted in the lateral direction and this becomes more noticeable in the case when waves meet an obstruction. An obstruction can be artificial break waters, natural reefs, submerged reefs or emerging reefs or even trenches and ridges can, will lead to the waves getting diffracted. So, we will try to understand, what exactly is this phenomenon, when by these two examples.

So, here in we have a rigid barrier which may be a break water and the waves are propagating form the deep waters. These are the wave crests; I am showing everything in plan; so, the wave crests are wave crests are wave troughs are moving. When I am dealing with this, I am assuming it is a constant water depth; the barrier is in a constant water depth. Please recollect, when we saw the phenomena of refraction, we observed that the phenomenon of refraction is mainly because of the waves propagating over varying water depth.

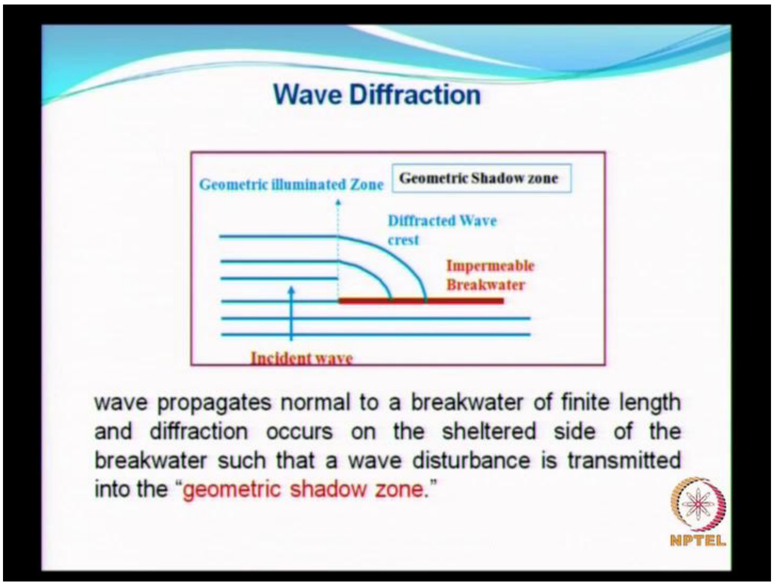
So, we will just keep that aside and we will just examine the phenomena of diffraction alone.So, for that purpose only we have considered only a constant water depth here. So, when you have a rigid barrier here and the wave crests come and meet the structure somewhere here, this is where it meets the structure, when it meets this area, this area will be an area with undisturbed wave crest. That is the wave crest will be moving as it is, it has been moving before being incident on the structure. But look at thisshadow over area. So, here in becauseafter the waves fill the tip of the structure, there is certain amount of energy being spread in the lateral direction because of which the wave fronts will start bending. So, you look at this bending of the waves. So, you see that the energy gets laterally diffracted. So, this is the phenomena of diffraction.

Now you look at this area. The same thing will happen; the same phenomena will happen here. So, naturally, the energy on the lee side of the break water, lee side of the break water, will be much less compared to this area, because these are unobstructed area where in the magnitude will remain same; this area too.Only here, the energy will be less compared to on either side of the, I mean, barrier. So, whenever you have a barrier because of this phenomenon of diffraction, the wave energy tries to penetrate; penetrate into the sheltered area. This is the reason why we have artificial harbours by constructing break waters.

So, you want to have calm water for the ship berthing or other loading and unloading operations in the harbor.You need not much of disturbance within the harbour and how do you achieve that? You can either have natural harbours or artificial harbours. Artificial harbors, you have a may be a pair of break waters, which we will see later.

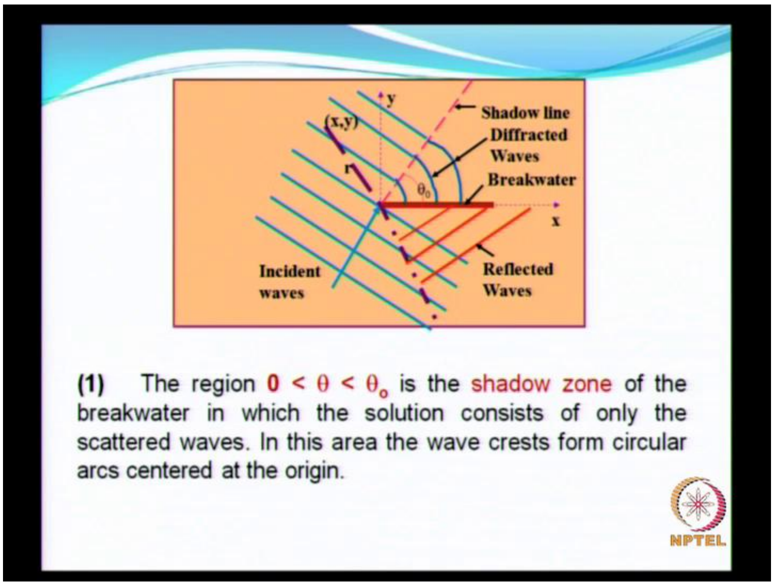
Now, we just look at the same diffraction phenomena with a pair of break waters. This is a classical example for when you try to develop an artificial harbor. So, normally you have a gap where in the ships will, the vessels will flow,move through the gap, and these are the break waters which are likely to offer you the, these are the two break waters which are likely to offer you the required tranquility; tranquility inside the harbour basin. So, when the waves enter here, you see that here it will be moving here; it will be moving uninterrupted but whereashere the energy will be diffracted. So, this area will be calmer zone compared to this area. So, I hope it is very clear now.

(Refer Slide Time: 06:29)



Now, we will move on to, we will again examine the same thing.When you have a rigid barrier, what would really happen? So, I am having a rigid barrier. Now, I am considering the simplest case. I am considering a simplest case that is I am having a barrier which is impermeable barrier. Why I call it as simplesimplest case because break water need not have to be impermeable; it may be permeable break water. When you consider permeable break water, then you have to find out how the energy is dissipated due to the presence of break water, etcetera. So, all these things are now avoided and we will just examine how the waves move around due to the presence of the structure. So, when you have a structure like this, the same way you have the bending of waves, as you see here and this is the geometric shadow area. What we have seen here, I am just again explaining to you by considering only one direction reaching the, I mean only one tip of the break water trying to explain how the waves bend. I hope this is clear. So, shall I go into the next slide?

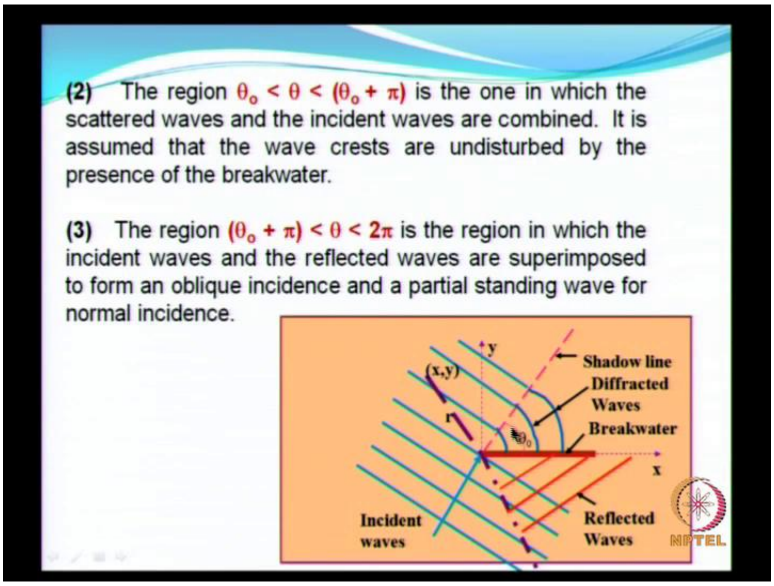
(Refer Slide Time: 07:57)



So, we will try to examine a bit more. By considering the same thing, we consider the normal angle of incidence, but the waves can approach from any angle. In this picture, we have a, we have a structure here and we see the waves coming in this direction. So, we will examine that there will be clearly three distinct zones. What are the three distinct zones? One is the angle, angle that it makes from zero to theta naught; this area or this zone is going to be having the bending of wave fronts and these are the diffracted waves.

Again, please remember that we aretalking only about constant water depth; we are talking only about a constant water depth.Now, what is the next zone? So, the first zone is theta up to zero to theta naught which is the shadow zone, presence of only the diffracted wave fronts.

(Refer Slide Time: 09:21)



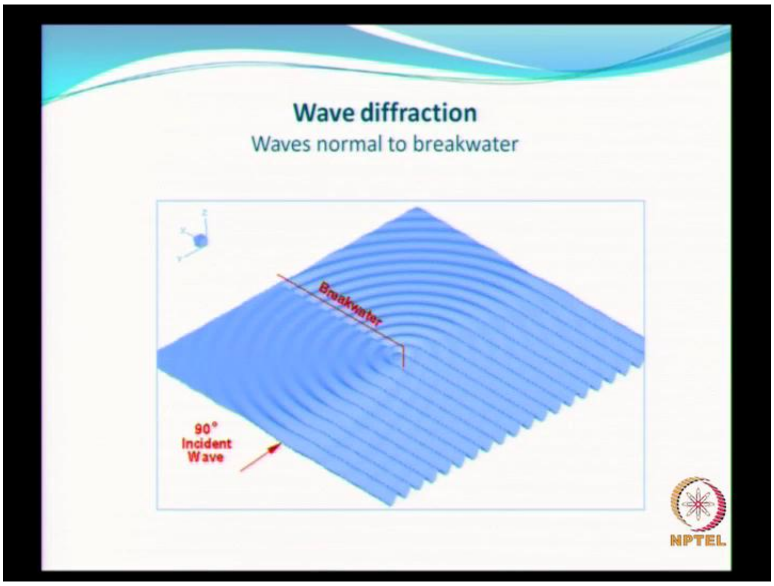
So, next comes theta, this area, as theta equal to theta naught; that is this form this to theta naught plus pi. So,I am talking about this area. What is this area? This area is uninterrupted; that is, you will have the wave fronts moving with the same amount of energy and same wave length because constant water depth.

In the same case, in the same condition, if this structure is going to be in a varying varying water depth, then this area, this area the wave fronts will not be of same magnitude or the I mean the speed or the wave length; everything will be changing; the wave characteristics will be changing. So, the last region will be this region, where we will have the phenomenon of combined effect of reflection from the structure and this will be, this will be superposed on the incident waves. The incident waves will be moving and then you have the reflected waves.In this case, we have considered an impermeable structure. Then, you will have only hundred percent reflected waves.

If there is permeability again, the percentage of reflection will vary.So, you see that there is a kind of complex phenomena that would be taking place, when you have a structure in the coastal area, in which casethe water depth is normally not constant. So, so the different conditions arise now. So, water depth constant, presence of break waters, that will lead to phenomena of diffraction, and plus reflection form the break water, break waters in a varying water depth, combined refraction of refraction, combined effect of refraction, diffraction,and reflection.

So for simple configurations it is easy for us to solve the problem. There are some analytical problems also, analytical solutions also, but for real problems, for practical for example, we will see later, how to how solve this. This phenomenon is considered in the field for practical problems. Then, you see that we mostly resort to either physical models or or numerical models.

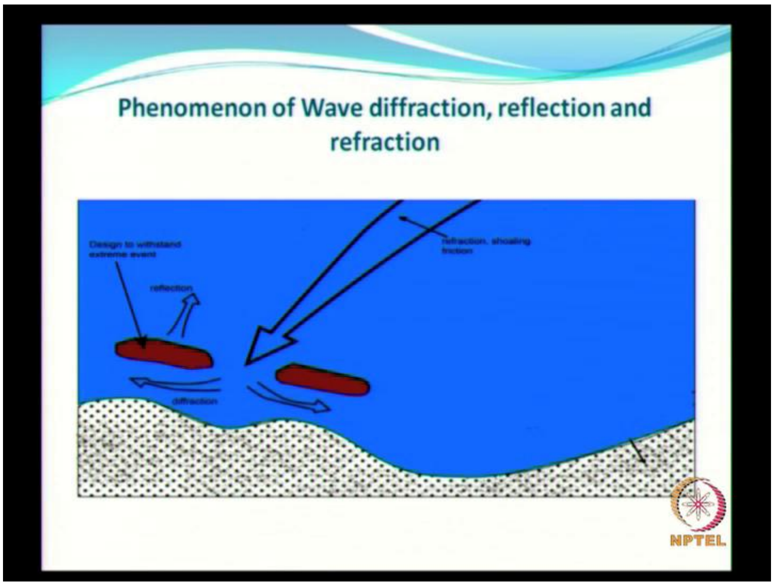
(Refer Slide Time: 12:35)



This is an animation wherein you see the break water here, the presence of break water. The waves are moving and after it is impinging on the structure, you see that this moves uninterrupted; this is what I was explaining earlier, and you look at the diffraction. And naturally here, the wave climate is expected to be very, very less. You look at this area; you see that you have the reflection taking place. So, this animation itself shows us the phenomena of diffraction very clearly.

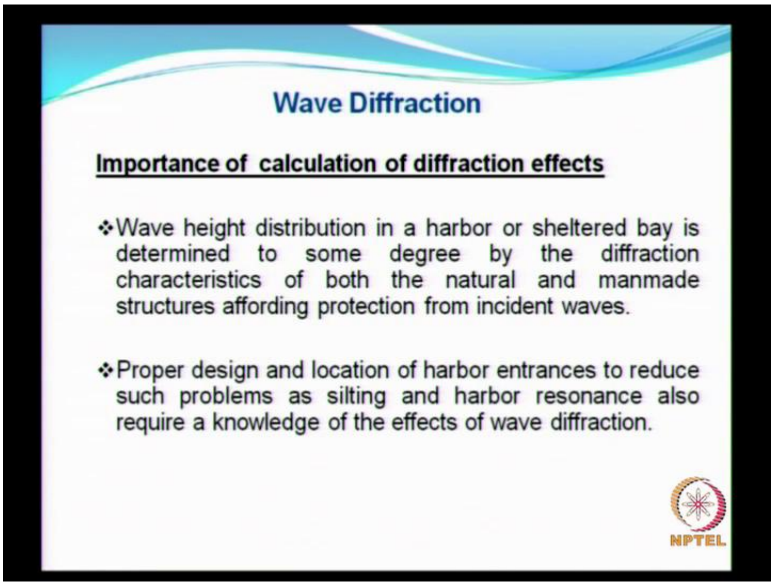
Now, you see that there is an oblique wave attack.So, you see that the bending of waves take place here and you see the reflection taking place here. And you can also have similar kind, you will also have similar kind of a phenomenon when you have a large structure or large island etcetera, and you see these scattering of waves and the lateral diffraction of the waves, wave energy; Is that clear? Some of all these animations have been provided to me by Professor CC Mei who is one of the well-known professors in the field of hydrodynamics, wave hydrodynamics.

(Refer Slide Time: 14:30)



When you look at this picture, whatever we have seen now that is just illustrated in this picture, where you see here because when the waves propagate, because of the varying water depth, you will have the phenomena of refraction, shoaling, and the as well as thebottom friction that is offered by the sea bed. And when it is moving towards, the wave orthogonals can converge or diverge which we have seen under the wave refraction and now presence of a obstructions like natural reefs, outcrops. For example, in India, tip of Indian peninsula, you have so many outcrops. All this outcrops can lead to some kind of, will lead to some kind of diffraction, certain extent of diffraction, and the presence of this will also lead to some amount of refraction. So, when you want to define, you want to take up some project, you have to consider all this phenomena before you plan for a major project.

(Refer Slide Time: 16:01)

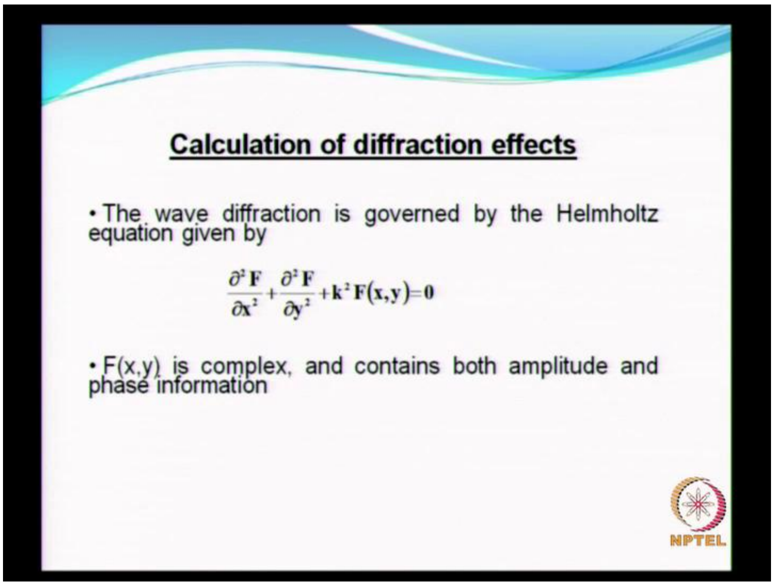


The phenomena of diffraction is extremely important.We are having seen what is meant by diffraction, we will now see what is the importance of diffraction? What is the importance? I have a here under mentioned earlier the importance, but here we will just go into the details.Wave height distribution in a harbor or a sheltered bay is determined to some degree by the diffraction characteristics of both the man and natural manmade structures, as well as the natural obstructions affording protection to the incident waves. Natural means what?

As I said earlier,outcrops,man-made is break waters.So, when you are planning for a major for a harbor, harbors can be either fishing harbors, a small minor harbors, or major harbors.Whatever it is, you need to know how you canalign the break waters. There are several, there are several ways of aligning your break water. Please remember that the main purpose of providing a break water is to absorb; to be most specific, to dissipate incident wave energy so that on the lee side of the breakwater, you will have calmer area.

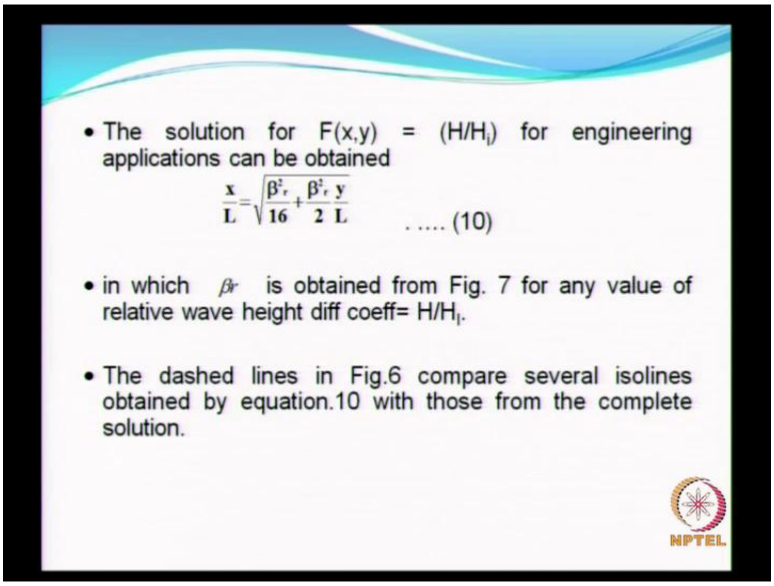
So, that is what it says here, proper design and location of harbor entrances to reduce such problems as silting and harbor resonance also require knowledge of wave diffraction. Particularly, when a very long period wave like a tsunami enters into a harbor, what will happen? The oscillation inside the harbor will continue for a very long time and when you have too much of oscillations inside the harbor, what will happen? The vessels which are anchored, anchored through moorings lines, it will be subjected to motions, and slack moorings can become taught and the moorings can snap and the collisions can take place, etcetera. So, when you plan for a harbor, what you normally do is, one is the predominant wave direction. You consider more or less the long period waves in that area and you try to align your break water and also fix up a gap between the break waters in such a way that you have minimum disturbance after the construction of break waters.

(Refer Slide Time: 19:30)



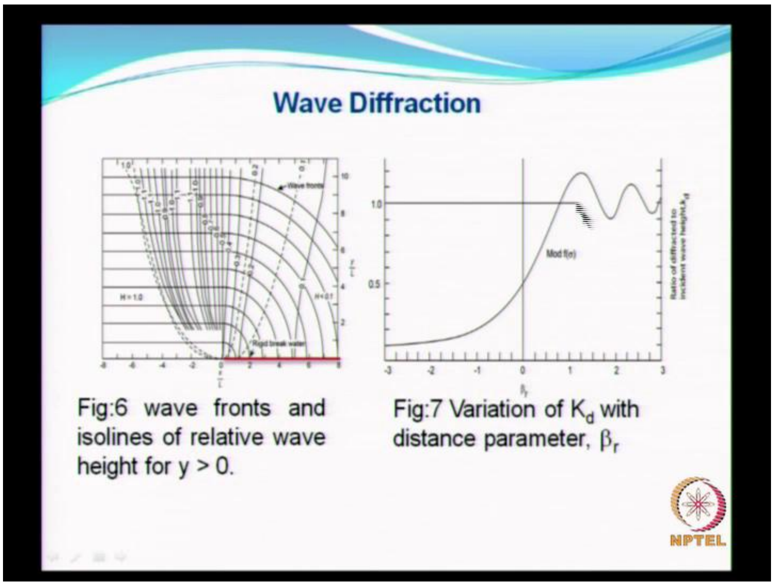
So, diffraction calculation is not so easy compared to what we have seen earlier, in the case of, compared to refraction. So, wave diffraction is governed by what is called as the helmholtz equation where this f of x y,x y is in the horizontal plane, is a complex and contains both amplitude and phase information.

(Refer Slide Time: 20:15)



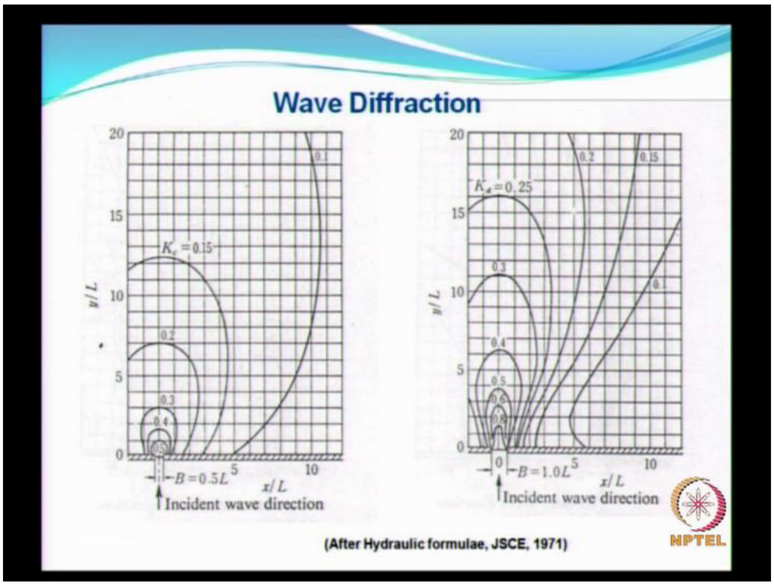
So, the solution to f of x y which is nothing butdirectly the relationship between, the ratio between the wave height inside the sheltered area to the incident wave height can be obtained as given here; x by l, one is nothing, x and y are the special coordinates and beta r can be obtained in the next figure; that is the next slide which I, whichyou have to see figure 7 in the next slide. So, you can obtain the value of the diffraction coefficient. I will show you the next figure.

(Refer Slide Time: 21:10)



You have a rigid break water here and this figure shows the wave fronts and the isolines of the relative wave height. So, these are the wave fronts and you see that this is a, this is your obstruction break water,and you see how the diffraction takes place.These are all the isolines of relative wave height that is nothing buttheir diffraction coefficient, andearlier slide we were mentioning about the distance parameter beta r that can be obtained using this picture,thisresult.In figure 6, again in the next slide, the dashed lines compare several isolines as obtained from equation 10. So, that are, that these are the dashed lines, which I am trying to show.

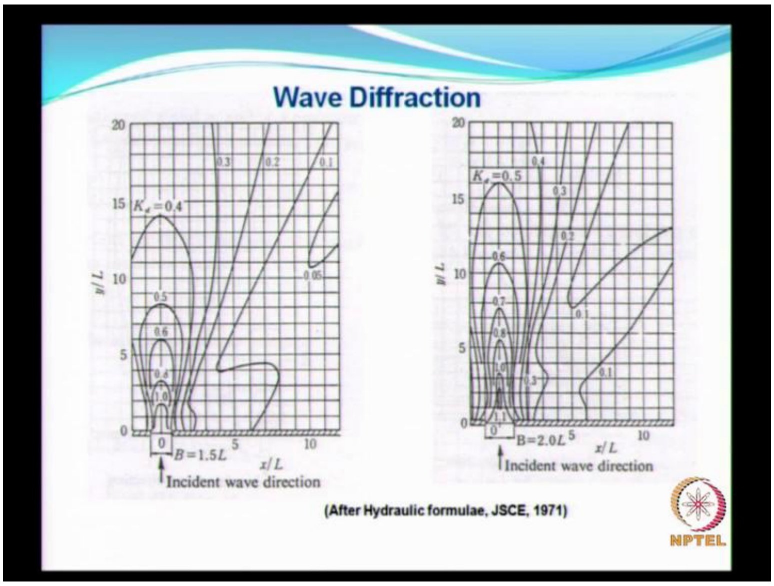
(Refer Slide Time: 22:41)



There are published literatures available which can be used to some extent like nomograms and this is after the hydraulic formulae from JSCE published in 1971, and these, also some of these results are available in a number of text books.Some of these text books are listed after atthe end of the lecture. So, what you see in this picture?On the left hand side, you see the break water, the gap between break break waters that is break water, the distance between the two break waters be equal to 0.5 times the wave length,0.5 times a wave length. So, you see that those curves, those are the isolines of constant k d or the diffraction coefficient.

On the right hand side, you see a similar picture for the break water gap equal to the wave length. So, naturally, if you keep increasingthe gap, your disturbance inside the area is going to increase. So, this is where you are see this is where you need to carefully design the harbor layout.

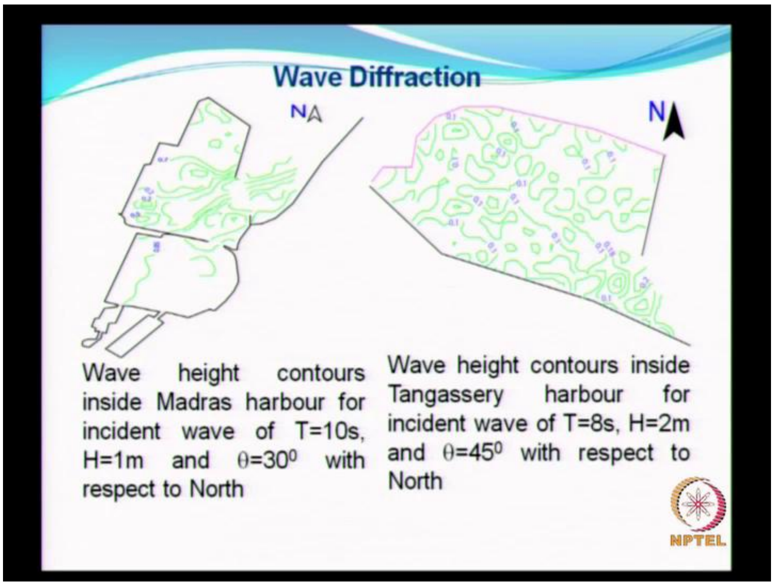
(Refer Slide Time: 24:20)



So, this picture on the left hand side shows the break water gap width equal to 1.5 five times the wave length. So, the gap between break waters is normally decided as a function of wave length and also the size of vessels, and also the type of traffic; that is whether it is going to be one way traffic or two way traffics etcetera. All those things are not going to covered in this lecture, but these are all a basic things,information you need before you finalize the harbor layout. So, on the right hand side, you seethe break water twice the wave length.So,all thisdisturbance keeps on increasing as the I mean as the gap increases.

So, you have four times wave length and five times the wave length how disturbance looks like. What you should do is you should carefully look at all these results once you sit down to understand the lecture. Then, you will be in a position to appreciate more. So, this again for 2.5 and three times the wave length.

(Refer Slide Time: 25:47)

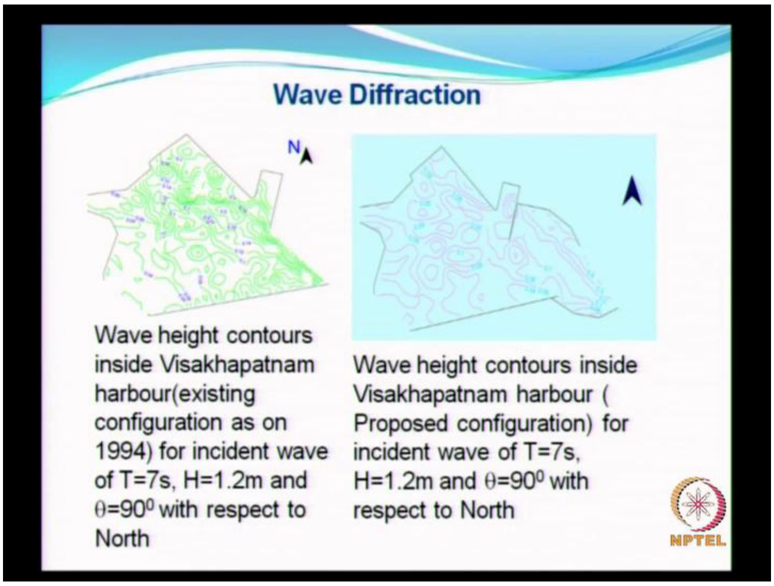


So, in our department, we have developed some basic models up to the advance models like, see basic models do not consider all the phenomena. One phenomena can be just considering it only as a, only the diffraction is considered. Is it correct or not? Yes or no? That is in the sense, if you have a break, if you have a harbor, you design the harbor for a given water depth.

So I can always say it is anyway constant water depth; so, I consider only diffraction, but major harbors, there can be variations in the water depth; then, you have to consider both the phenomena so that the problem becomes more and more complicated; so, you resort automatically to numerical models. So, this shows how wave height contours look like when a wave on the left side you have the Chennai harbor, one of the major harbor; on the right side you have the layout of Tangassery fishing harbor. So, remember the break water can be impermeable or permeable.

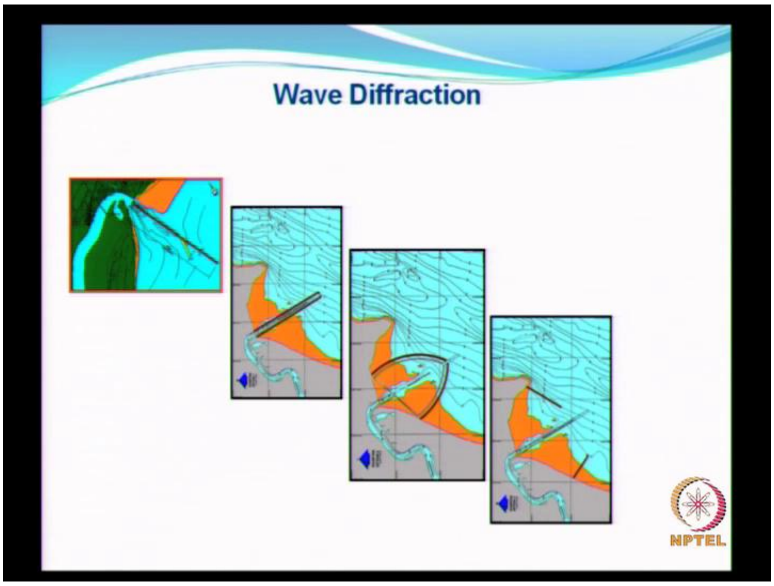
Most of our break waters are permeable, which is advantageous? Permeable only is advantageous because it will amount to certain amount of, it will account for certain amount of dissipation of incident waves. So, we get lot of information. Once you try to have this kind of information, you want to do some alterations within the existing harbor, then you can always feed into your numerical model and try to understand what is going to happen, if you are going to change some of the items inside the harbor.

(Refer Slide Time: 28:12)



So, this is another, this is thethis is Visakhapatnam port wherein you have the eastern break water here, and what we have to try to do is, we have on the right side you see the two projections of two break waters. That was tried out as an exercise to check how the tranquility would be improved by having those two arms. Can we improve the tranquility further from the existing ones with the existing ones? So, of course, this is going to yield good results. Then the point of cost benefit aspect also comes into picture. By having those two arms, yes we have the calmer area, butstill will it be really worth it? So, all these things come as a continuation of the project before taking the decision. So, all these information will be very helpful that leads to the decision making.

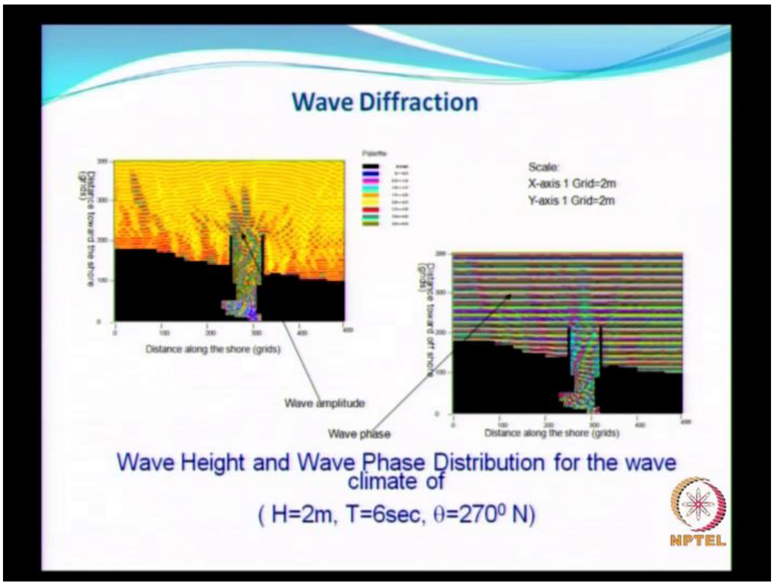
(Refer Slide Time: 29:20)



So, this is another example showing you how this diffraction calculation can be useful particularly in the case of layout of harbors. For example, here, we have a river mouth we have a river mouth. So, there is some amount of waves. Mostly, the waves are coming in this direction. Sometimes waves are coming from this direction too. Sorry, it moves in this direction; so can we have only one single break water or can we go in for two break waters like this, allowing the vessels to move into to this. Then you try to find out the diffraction through the break waters and try to arrive at the wave energy or can we have because you want to have some more, I mean, area for this can we have two curved break waters like this, or can we have two break waters as shown here.

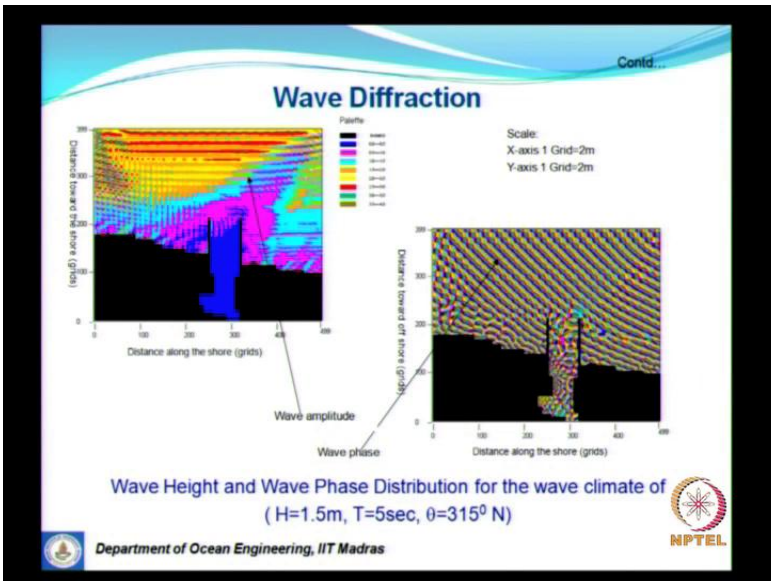
So, for a given location, you have different deferent kinds of configuration which you can examine. In earlier days, this used to be done with physical models, only with physical models, mostly with physical models, but now you see that computers have becomes so cheap, etcetera. All over the world, they now resort more towards, they consider numerical models compared to physical models for understanding such effects.

(Refer Slide Time: 31:25)



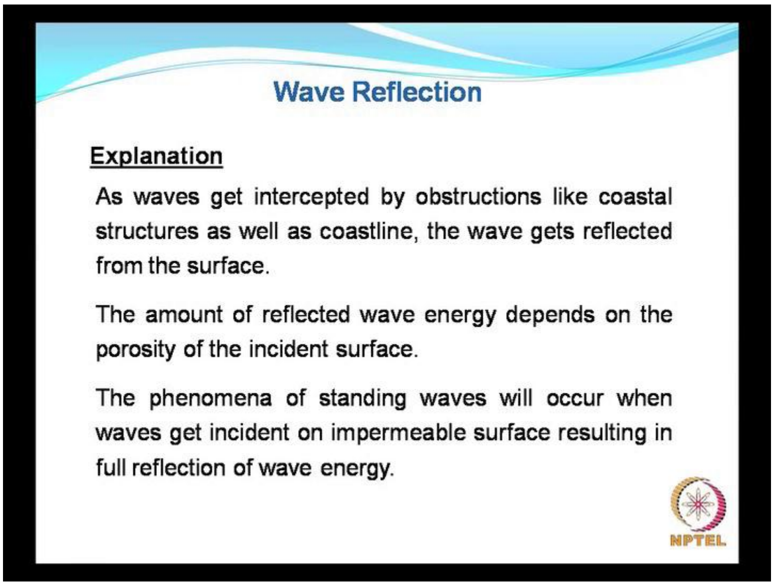
This is what we have done in our laboratory in our department wherein you see the on the left side, you see the wave height contours on the left side; on the right side, you see the waves penetrating directly. As you see here, the waves are approaching normal to the shore line, more or less. So, this picture would give us what is the extent of a tranquility and what is the wave kind of wave energy or wave height you would have, and will it be within the permissible limit when a vessel is travelling etcetera, when when the vessel is moving.

(Refer Slide Time: 32:11)



So, here, earlier we saw normal wave angle angle of incidence. Now, we have the, so this is called as phase contours wherein this shows how the waves are trying to move. And you look at this. You see that the waves are bending and waves are bending, and then once itenters a narrow area, it becomes complicated because you have a reflection form the side break waters, etcetera. So, you will have a different issue.

(Refer Slide Time: 32:40)

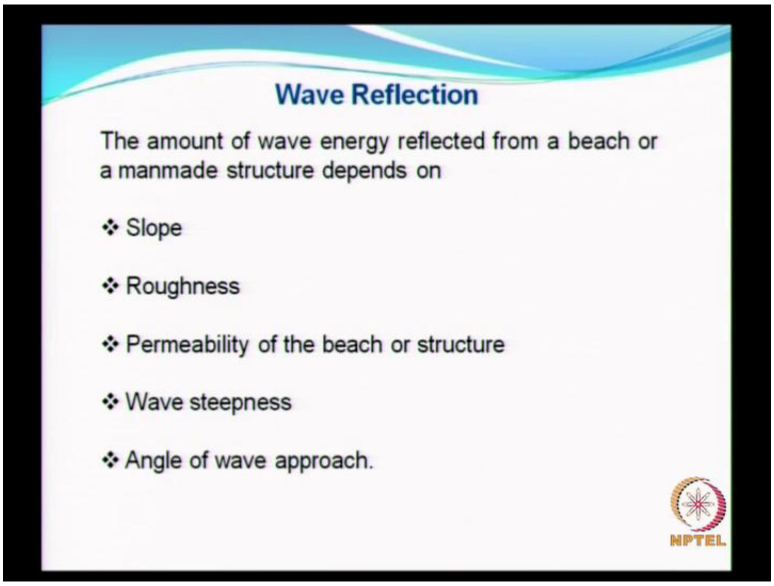


So, I am sure that you have got good good exposure to the diffraction today, wave diffraction. So, we saw what is what was what is the phenomena of wave diffraction, what is its importance, and as well as where do you apply and how do you apply. The next topic will be on wave reflection.

As waves get intercepted by obstructions like coastal structures as well as coastal line, coast line, the wave gets reflected form the surface. The amount of reflected wave energy depends on the type of structure, beach slope, the incident wave characteristics, and in fact, shape of the structure; shape of the structure in the sense, what I am trying to say is whether it is a sloping wall or a vertical wall. If it is a vertical wall impermeable, entire energy is going to be reflected back which is termed as clopaities which we have seen earlier.

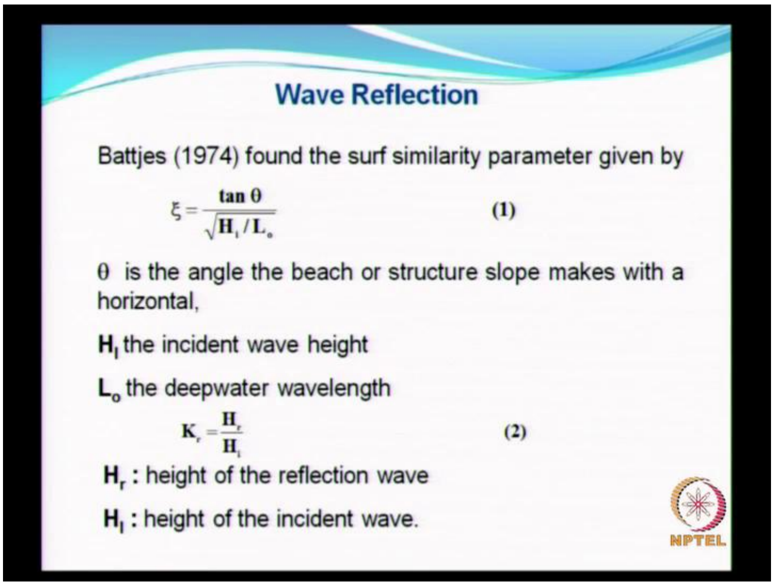
If it is going to be vertical, you have maximum reflection and if it is going to be inclined the reflection is going to be reduced. Why reflection is important? Would you like to have reflection or not? Reflection is not that desirable, why? Because when the wave is trying to move, propagate, you are putting an obstruction, because of which what happens? In the vicinity of the structure, the wave energy increases. In fact, the wave height can become double, the incident wave height. So, when the wave height increases, the forces increase and there is other associated phenomena like cover under the structure, under the toe, etcetera. All these things create problems. So, there have been enough efforts these days trying to bring in porous structures in order to reduce reflection; you understand?

(Refer Slide Time: 35:43)



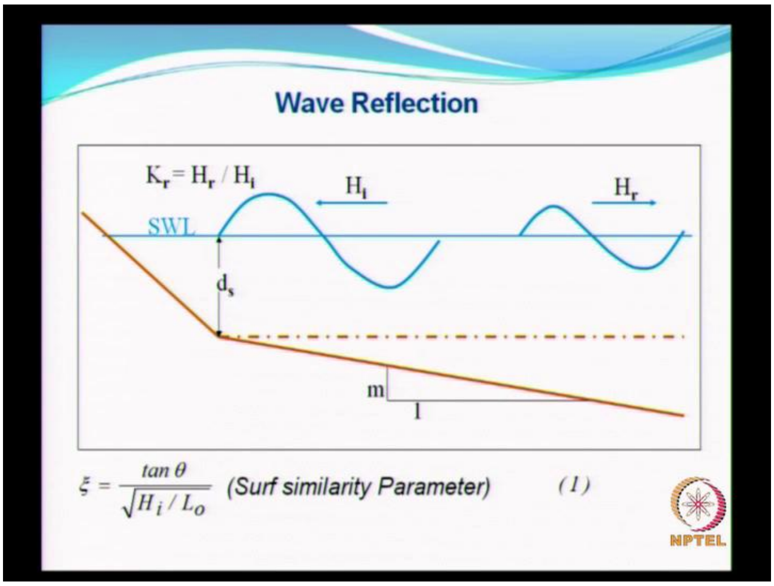
So, this I have already explained. Once again, let us see this the amount of wave energy reflected form a beach or a manmade structure depends on the beach slope, the roughness, permeability of the beach or the structure, wave steepnessas well as the angle of wave approach.

(Refer Slide Time: 36:10)



Battjes in 1974, he introduced a parameter, which is called as surf similarity parameter; that is given as a ratio of the beach slope to the wave steepness. So, here Hi is the incident wave height,L naught is the deep water wave height, and we are looking at k r; k r is nothing butas we saw in diffraction coefficient k d which is equivalent to diffracted coefficient divided by the incident wave height. Here, we have the reflection reflection coefficient where in it is the ratio of reflected wave height to the incident wave height.

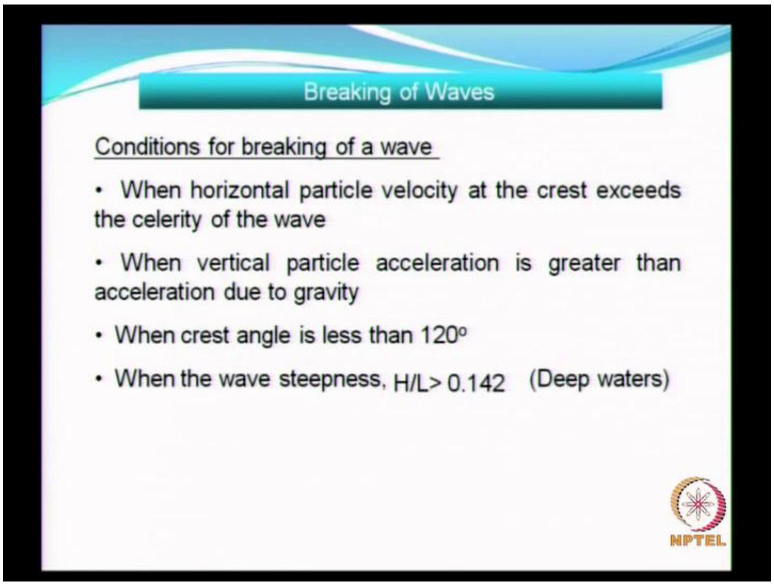
(Refer Slide Time: 36:56)



So, this picture gives clearly the various parameters that are variables that are associated with the wave with the wave reflection. k r is H r by Hi and Hi is incident wave height, reflected wave height. You look at the slope. So, when the slope is there, H r will be less and now this is what is called as the surf similarity parameter which we have seen earlier. For additional information on wave reflection, you can refer a number of books or…

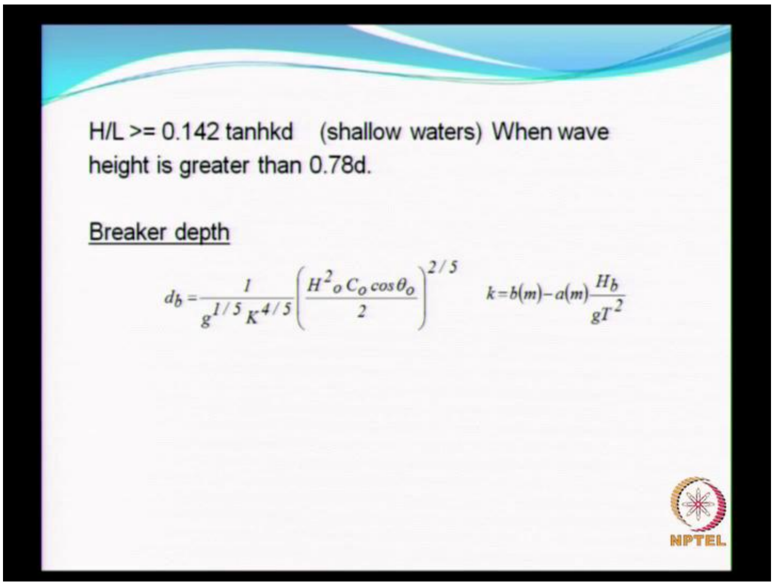
So, now, let us move into another important area of breaking of waves. So, when you go to a beach, what what do you see? When you stand in front of on the beach and look into the ocean. What do you see? You see the waves breaking in front of you. Beyond the waves, wave breaking, you see some waves moving without breaking. And then, once a wave breaks, what happens? You will have gentle oppress of the waves. But we do not really notice if there is any kind of difference between the wave breaking along may be south east cost of India or along the coast of Goa. You really do not see for a lay man, wave breaking is wave breaking; that is all, but for us, after undergoing this course, you will really understand the difference between or the classification of breaking of waves.Understood?

(Refer Slide Time: 39:11)



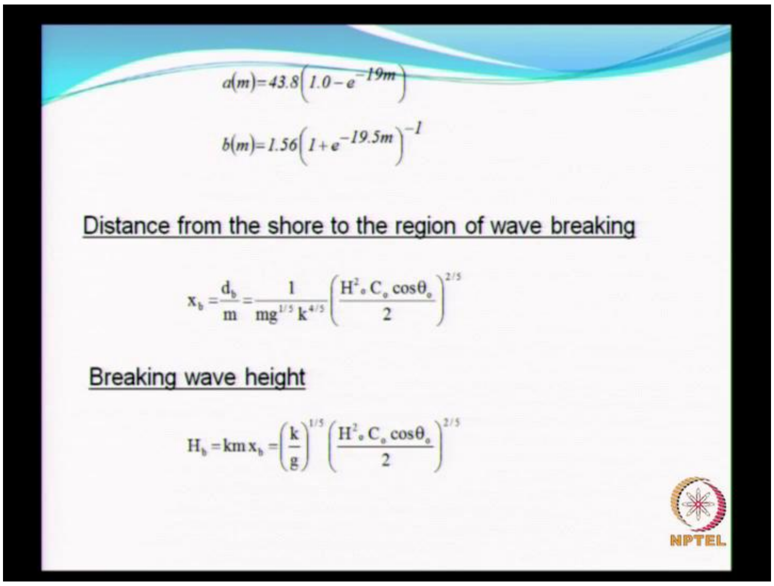
So, let us look at the breaking of waves. There are some several conditions when the horizontal water particle velocity at the crest exceeds the celerity that is the velocity when you have the crest of the wave. When you have the crest of the wave, the velocity corresponding to the crest of the wave; when that velocity exceeds the celerity, speed of the wave, when the vertical particle acceleration is greater than acceleration due to gravity; when the crest angle is less than 120 degree, that is another criteria; it is not that a popular. And when the wave steepness is exceeding 0.142 in the case of deep watersand that 0.142 has to be multiplied by tan H tan hyperbolic k d in the case of other than deep waters.

(Refer Slide Time: 40:26)



And finally, there is one more criteria which is 0.78 times water depth that is when the wave height is exceeding 0.78 times water depth. There are other criteria for example, now all the other earlier empirical relations or all empirical relationships which does not consider the beach slope into account. So, there is another formula wherein as you have as you have here, herein this k is given by this parameter and a (m) and b(m) are the parameters given here.

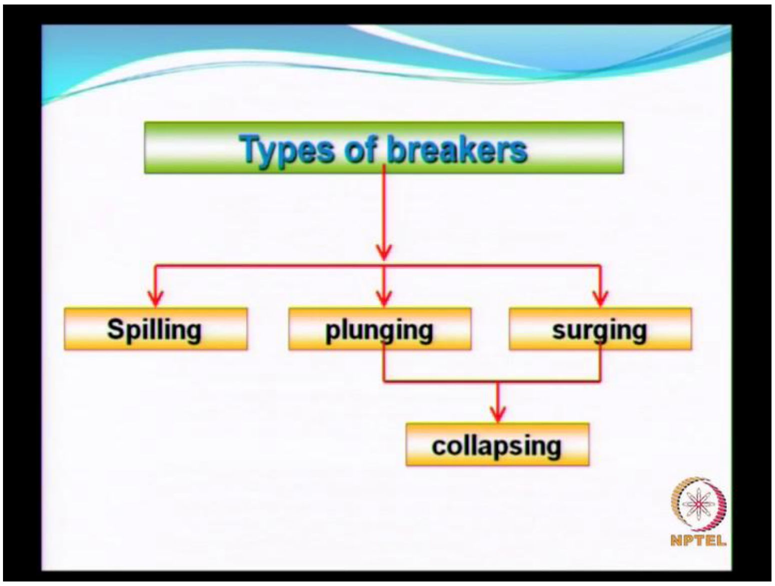
(Refer Slide Time: 41:22)



So, this, the parameters a(m) and b(m) are provided here where in m is the beach slope. So, you need to go through a kind of an iteration to arrive at the breaker depth, if you want to consider the beach slope also. And once you know this slope, you know that the surf width can be calculated as d b that is a depth of breaking to the beach slope.

So, using the above formulae, you can finally arrive at your breaker wave height as a function of the deep water deep water wave height, deep water celerity, deep water direction. So, this formula will consider considers the beach slope, deep water wave height, deep water celerity as well as deep water direction. So, I will thus run through the formulas again. So, this is the break water depth. The break water depth is going to be a function of all those deep water wave characteristics, where in you have k equal to as a function of breaker wave height and the beach slope, and a and b m are given are functions of beach slope, and with thiswe can easily calculate here breaker wave height. Any way, we will try to work out a problem, so that things will be more clear.

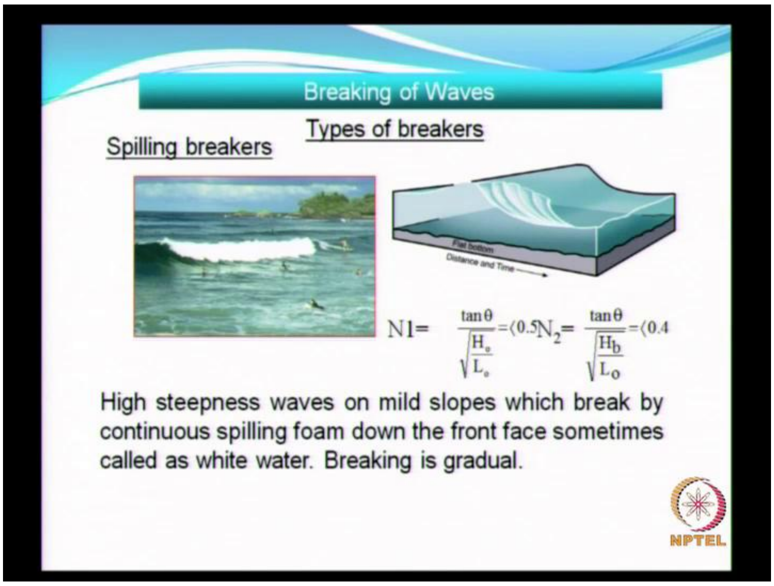
(Refer Slide Time: 43:14)



Now, we will move on to types of breakers.When you, when we look into type of breaker, why is it important? Why are we studying about breaking of waves? From structural point of view, when you have a structure and the waves come and hit the structure, the force you exerted is an impact force. So, it is like this. So, its exists only for a short duration, butthe magnitude is quite high and it is a set in literature that the braking wave force can vary from something like 8 to 15 times the non-breaking wave force. That is from structures point of view butwhen the waves are breaking near the shallow waters, you see the beach has been built up the distribution of sand is quite important if you want to have good beaches etcetera. This depends on the type of breaking; not only that the surfing why a certain beaches alone very popular.

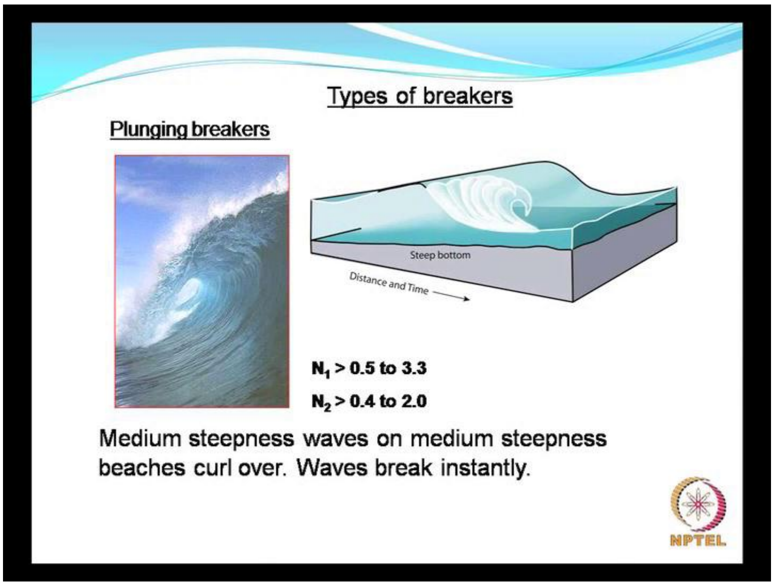
When you have very flatslopes, then you say, you see that the waves breaking may be kind of gentle breaking; you do not want violent kind of breaking. And not only that the nature of a beach along the coast depends on how the sand is getting sorted out while it is entrapped in the breaker zone. So, these are all some other fields of specialization, but you should know that this is why you are trying to understand the different types of breaking of waves. So, you have spilling type of breakers, plunging type of breaking, surging type of breakers, and there is a classification in between plunging and surging which is called as collapsing.

(Refer Slide Time: 46:07)



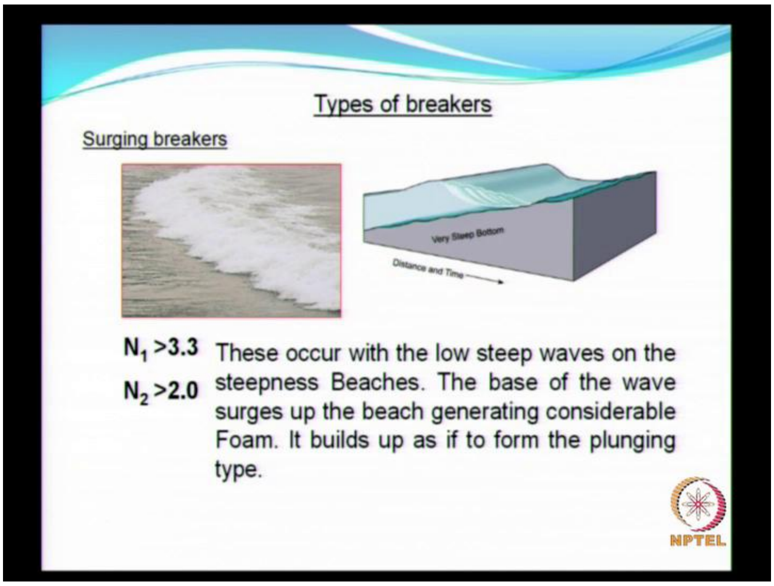
The picture at the background shows a spilling breaker. High steepness waves on mild slopes, which break continue by continuous spelling continuous spelling foam down the front phase and this is almostalways sometimes called as white water and breaking is gradually. For example, Goa beaches; very popular; so, you can walk for a long distance. And is there any parameter to describe this? Yes. There is a parameter N 1 and N 2 and all these parameters are already known to you.This is less than N 1 should be approximately less than 0.5 whereas N 2 should be less than 0.4, normally you have deep water wave characteristics; so, N 1 is the one which is normally used.

(Refer Slide Time: 47:19)



Then comes the plunging type of breakers, and I am sure that you would have seen a number of advertisements also wherein you have plunging breakers. It looks very nice and when does this occur? When medium steep waves or medium steepness steep beaches and the waves curl around, and the breaking is instantaneous, it instantly breaks and it also creates sound when it breaks.

(Refer Slide Time: 47:59)



Then surging type of breakers: These occurs with thelowest steeper waves on very steep beaches and the base of the wave, the base of the waves, tries to surge up the beach as if it is going to generating considerable amount of foam as if it is going to form as a plunging type of breakers.